

## **Appendix E.**

### **SOP – Operation of TSP High Volume Air Sampler**

- Sampler Operation
- Digital Timer Operation (refer to Appendix D)
- Total Volume Calculations (refer to Appendix D)

## SAMPLER OPERATION TE-5170-D MFC TSP

1. After performing calibration procedure, remove filter holder frame by loosening the four wing nuts allowing the brass bolts and washers to swing down out of the way. Shift frame to one side and remove.
2. Carefully center a new filter, rougher side up, on the supporting screen. Properly align the filter on the screen so that when the frame is in position the gasket will form an airtight seal on the outer edges of the filter.
3. Secure the filter with the frame, brass bolts, and washers with sufficient pressure to avoid air leakage at the edges (make sure that the plastic washers are on top of the frame).
4. Wipe any dirt accumulation from around the filter holder with a clean cloth.
5. Close shelter lid carefully and secure with the "S" hook.
6. Make sure all cords are plugged into their appropriate receptacles and the rubber tubing between the blower motor pressure tap and the TE-5009 continuous flow recorder (or TE-5008 manometer) is connected (be careful not to pinch tubing when closing door).
7. Prepare TE-5009 continuous flow recorder as follows:
  - a) Clean any excess ink and moisture on the inside of recorder by wiping with a clean cloth.
  - b) Depress pen arm lifter to raise pen point and carefully insert a fresh chart.
  - c) Carefully align the tab of the chart to the drive hub of the recorder and press gently with thumb to lower chart center onto hub. Make sure chart is placed under the chart guide clip and the time index clip so it will rotate freely without binding. Set time by rotating the drive hub clock-wise until the correct time on chart is aligned with time index pointer.
  - d) Make sure the TE-160 pen point rests on the chart with sufficient pressure to make a visible trace.
8. Prepare the Timer as instructed on page 20.
9. At the end of the sampling period, remove the frame to expose the filter. Carefully remove the exposed filter from the supporting screen by holding it gently at the ends (not at the corners). Fold the filter lengthwise so that sample touches sample.
10. It is always a good idea to contact the lab you are dealing with to see how they may suggest you collect the filter and any other information that they may need.

## **Appendix F.**

### **SOP – Calibration of PM<sub>10</sub> and TSP High Volume Air Samplers**

## CALIBRATION PROCEDURE-Mass Flow Controlled TE-6070, TE-6070D

The following is a step-by-step process for the calibration of TE-6070, TE-6070D Mass Flow Controlled PM10 High Volume Sampling Systems. Following these steps are example calculations determining the calibration flow rates, and resulting slope and intercept for the sampler. These instructions pertain to the samplers that have flow controlled by electronic mass flow controllers (MFC) in conjunction with a continuous flow recorder. This calibration differs from that of a volumetric flow controlled sampler. The attached example calibration worksheets can be used with either a TE-5025 Fixed Orifice Calibrator that utilize resistance plates to simulate a variation in airflow or a TE-5028 Variable Orifice Calibrator which uses an adjustable or variable orifice. The attached worksheet uses a variable orifice. Either type of orifice is acceptable for calibrating high volume samplers the calibration process remains the same. Proceed with the following steps to begin the calibration:

Proceed with the following steps to begin the calibration:

**Step one:** Disconnect the sampler motor from the mass flow controller and connect the motor to a stable AC power source.

**Step two:** Mount the calibrator orifice and top loading adapter plate to the sampler. A sampling filter is generally not used during this procedure. Tighten the top loading adapter hold down nuts securely for this procedure to assure that no air leaks are present.

**Step three:** Allow the sampler motor to warm up to its normal operating temperature.

**Step four:** Conduct a leak test by covering the hole on top of the orifice and pressure tap on the orifice with your hands. Listen for a high-pitched squealing sound made by escaping air. If this sound is heard, a leak is present and the top loading adapter hold-down nuts need to be re-tightened.

**“WARNING”** Avoid running the sampler for longer than 30 seconds at a time with the orifice blocked. This will reduce the chance of the motor overheating.

**“WARNING”** never try this leak test procedure with a manometer connected to the side tap on the calibration orifice or the blower motor. Liquid from the manometer could be drawn into the system and cause motor damage.

**Step five:** Connect one side of a water manometer to the pressure tap on the side of the orifice with a rubber vacuum tube. Leave the opposite side of the manometer open to the atmosphere.

**Note:** Both valves on the manometer have to be open for the liquid to flow freely also to read a manometer one side of the 'U' tube goes up the other goes down; add together this is the "H<sub>2</sub>O

**Step six:** Turn black knob on top of calibrator (TE-5028A) counter clock-wise opening the four holes on the bottom wide open. Record the manometer reading from the orifice and the continuous flow recorder reading from the sampler. A manometer must be held vertically to insure accurate readings. Tapping the backside of the continuous flow recorder will help to center the pen and give accurate readings. Repeat this procedure by adjusting the knob on the orifice to five different reading. Normally the orifice reading should be between 3.0" and 4.0" of H<sub>2</sub>O. If you are using a fixed orifice (TE-5025A), five flow rates are achieved in this step by changing 5 different plates (18,13,10,7, and 5 hole plates) and taking five different readings.

**Step seven:** Record the ambient air temperature, the ambient barometric pressure, the sampler serial number, the orifice s/n, the orifice slope and intercept with date last certified, today's date, site location and the operator's initials.

**Step eight:** Disconnect the sampler motor from its power source and remove the orifice and top loading adapter plate. Re-connect the sampler motor to the electronic mass flow controller.

An example of a PM10 Sampler Calibration Data Sheet has been attached with data filled in from a typical calibration. This includes the transfer standard orifice calibration relationship which was taken from the Orifice Calibration Worksheet that accompanies the calibrator orifice. Since this calibration is for a PM10 sampler, the slope and intercept for this orifice uses **actual** flows rather than standard flows and is taken from the Q<sub>actual</sub> section of the Orifice Calibration Worksheet. The Q<sub>standard</sub> flows are used when calibrating a TSP sampler.

The five orifice manometer readings taken during the calibration have been recorded in the column on the data worksheet titled "H<sub>2</sub>O. The five continuous flow recorder readings taken during the calibration have been recorded under the column titled I (chart).

The orifice manometer readings need to be converted to the actual airflows they represent using the following equation:

$$Q_a = 1/m[\text{Sqrt}((H_2O)(T_a/P_a))-b]$$

where:  $Q_a$  = actual flow rate as indicated by the calibrator orifice,  $m^3/\text{min}$   
 $H_2O$  = orifice manometer reading during calibration, (inches)  $H_2O$

$T_a$  = ambient temperature during calibration, K (  $K = 273 + ^\circ\text{C}$ )

$P_a$  = ambient barometric pressure during calibration, mm Hg

$m$  = *Q*actual slope of orifice calibration relationship

$b$  = *Q*actual intercept of orifice calibration relationship.

Once these actual flow rates have been determined for each of the five run points, they are recorded in the column titled  $Q_a$ , and are represented in cubic meters per minute.

The continuous flow recorder readings taken during the calibration need to be corrected to the current meteorological conditions using the following equation:

$$IC = I[\text{Sqrt}(T_a/P_a)]$$

where:  $IC$  = continuous flow recorder readings corrected to current  $T_a$  and  $P_a$

$I$  = continuous flow recorder readings during calibration

$P_a$  = ambient barometric pressure during calibration, mm Hg.

$T_a$  = ambient temperature during calibration, K (  $K = 273 + ^\circ\text{C}$ )

After each of the continuous flow recorder readings have been corrected, they are recorded in the column titled  $IC$  (corrected). Using  $Q_a$  and  $IC$  as the  $x$  and  $y$  axis respectively, a slope, intercept, and correlation coefficient can be calculated using the least squares regression method. The correlation coefficient should never be less than 0.990 after a five point calibration. A coefficient below .990 indicates a calibration that is not linear and the calibration should be performed again. If this occurs, it is most likely the result of an air leak during the calibration.

The equations for determining the slope ( $m$ ) and intercept ( $b$ ) are as follows:

$$m = \frac{\frac{(\sum x)(\sum y)}{\sum xy} - \frac{n}{n}}{\frac{(\sum x)^2}{\sum x^2} - \frac{n}{n}} ; \quad b = \bar{y} - m\bar{x}$$

where:  $n$  = number of observations  $\bar{y} = \sum y/n$ ;  $\bar{x} = \sum x/n$   $\Sigma$  = sum of

The equation for the coefficient of correlation (r) is as follows:

$$r = \frac{\sum xy - \frac{(\sum x)(\sum y)}{n}}{\sqrt{\left[ \sum x^2 - \frac{(\sum x)^2}{n} \right] \left[ \sum y^2 - \frac{(\sum y)^2}{n} \right]}}$$

where:    n    = number of observations  
              Σ    = sum of

### Example Problems

The following example problems use data from the attached calibration worksheet.

After all the sampling site information, calibrator information, and meteorological information have been recorded on the worksheet, standard air flows need to be determined from the orifice manometer readings taken during the calibration using the following equation:

$$1. \quad Q_a = 1/m[\text{Sqrt}((H_2O)(T_a/P_a)) - b]$$

where:    Q<sub>a</sub>    = actual flow rate as indicated by the calibrator orifice, m<sup>3</sup>/min  
              "H<sub>2</sub>O    = orifice manometer reading during calibration, (inches) "H<sub>2</sub>O  
              T<sub>a</sub>    = ambient temperature during calibration, K ( K = 273 + °C)  
              P<sub>a</sub>    = ambient barometric pressure during calibration, mm Hg  
              m    = *Q*<sub>actual slope of orifice calibration relationship</sub>  
              b    = *Q*<sub>actual intercept of orifice calibration relationship</sub>.

Note that the ambient temperature is needed in degrees Kelvin to satisfy the Q<sub>a</sub> equation. Also, the barometric pressure needs to be reported in millimeters of mercury. In our case the two following conversions may be needed:

$$2. \quad \text{degrees Kelvin} = [5/9 (\text{degrees Fahrenheit} - 32)] + 273$$

$$3. \quad \text{millimeters of mercury} = 25.4(\text{inches of H}_2\text{O}/13.6)$$

Inserting the numbers from the calibration worksheet run point number one we get:

$$4. \quad Q_a = 1/.99486 [\text{Sqrt}((5.45)(294/753)) - (-.00899)]$$

$$5. \quad Q_a = 1.005 [\text{Sqrt}((5.45)(.390)) + .00899]$$

$$6. \quad Q_a = 1.005 [\text{Sqrt}(2.1255) + .00899]$$

7.  $Q_a = 1.005[1.4579 + .00899]$

8.  $Q_a = 1.005[1.46689]$

9.  $Q_a = 1.474$

Throughout these example problems you may find that your answers vary some from those arrived at here. This is probably due to different calculators carrying numbers to different decimal points. The variations are usually slight and should not be a point of concern. Also, with a good calibration there should be at least three  $Q_a$  numbers in the range of 1.02 to 1.24 m<sup>3</sup>/min (36 to 44 CFM). From the data sheet there is 4 out of 5 numbers in the range for PM10 thus a good calibration.

With the  $Q_a$  determined, the corrected chart reading (IC) for this run point needs to be calculated using the following equation:

10.  $IC = I[\text{Sqrt}(T_a/P_a)]$

where:  $IC$  = continuous flow recorder readings corrected to current  $T_a$  and  $P_a$   
 $I$  = continuous flow recorder readings during calibration  
 $P_a$  = ambient barometric pressure during calibration, mm Hg.  
 $T_a$  = ambient temperature during calibration, K (  $K = 273 + ^\circ\text{C}$  )

Inserting the data from run point one on the calibration worksheet we get:

11.  $IC = 56 [\text{Sqrt}(294/753)]$

12.  $IC = 56 [\text{Sqrt}(.390)]$

13.  $IC = 56 [.6244997]$

14.  $IC = 34.97$

This procedure should be completed for all five run points. EPA guidelines state that at least three of the five  $Q_a$  flow rates during the calibration be within or nearly within the acceptable operating limits of 1.02 to 1.24 m<sup>3</sup>/min (36 to 44 CFM). If this condition is not met, the instrument should be recalibrated.

Using  $Q_a$  as our x-axis, and  $IC$  as our y-axis, a slope, intercept, and correlation coefficient can be determined using the least squares regression method.

The equations for determining the slope (m) and intercept (b) are as follows:

$$15. \quad m = \frac{\frac{(\sum xy)}{n} - \frac{(\sum x)(\sum y)}{n^2}}{\frac{(\sum x^2)}{n} - \frac{(\sum x)^2}{n^2}} ; \quad b = \bar{y} - m\bar{x}$$

where:  $n$  = number of observations

$$\bar{y} = \Sigma y/n; \quad \bar{x} = \Sigma x/n \quad \Sigma = \text{sum of.}$$

The equation for the coefficient of correlation (r) is as follows:

$$16. \quad r = \frac{(\Sigma xy) - \frac{(\Sigma x)(\Sigma y)}{n}}{\sqrt{\left[ \Sigma x^2 - \frac{(\Sigma x)^2}{n} \right] \left[ \Sigma y^2 - \frac{(\Sigma y)^2}{n} \right]}}$$

where:  $n$  = number of observations

$\Sigma$  = sum of.

Before these can be determined, some preliminary algebra is necessary.  $\Sigma x$ ,  $\Sigma y$ ,  $\Sigma x^2$ ,  $\Sigma xy$ ,  $(\Sigma x)^2$ ,

$(\Sigma y)^2$ ,  $n$ ,  $y$ , and  $x$  need to be determined.

$$17. \quad \Sigma x = 1.475 + 1.167 + 1.115 + 1.079 + 1.060 = 5.896$$

$$18. \quad \Sigma y = 35.00 + 29.37 + 28.75 + 28.12 + 27.50 = 148.74$$

$$19. \quad \Sigma x^2 = (1.475)^2 + (1.167)^2 + (1.115)^2 + (1.079)^2 + (1.060)^2 = 7.069$$

$$20. \quad \Sigma y^2 = (35.00)^2 + (29.37)^2 + (28.75)^2 + (28.12)^2 + (27.50)^2 = 4461.1438$$

$$21. \quad \Sigma xy = (1.475)(35.00) + (1.167)(29.37) + (1.115)(28.75) + (1.079)(28.12) + (1.060)(27.50) = 177.448$$

$$22. \quad n = 5$$

$$23. \quad \bar{x} = \Sigma x/n = 1.1792$$

$$24. \quad \bar{y} = \Sigma y/n = 29.748$$

$$25. \quad (\Sigma x)^2 = (5.896)^2 = 34.763$$

$$26. \quad (\Sigma y)^2 = (148.74)^2 = 22,123.587$$

Inserting the numbers:

$$27. \quad \text{slope} = \frac{177.448 - \frac{(5.896)(148.74)}{5}}{7.069 - \frac{34.763}{5}}$$

$$28. \quad \text{slope} = \frac{177.448 - \frac{(876.971)}{5}}{7.069 - \frac{34.763}{5}}$$

$$29. \quad \text{slope} = \frac{177.448 - 175.394}{7.069 - 6.953}$$

$$30. \quad \text{slope} = \frac{2.054}{0.116}$$

$$31. \quad \text{slope} = 17.707$$

$$32. \quad \text{intercept} = 29.748 - (17.707)(1.1792)$$

$$33. \quad \text{intercept} = 29.748 - 20.88$$

$$34. \quad \text{intercept} = 8.868$$

$$35. \quad \text{correlation coeff.} = \frac{(5.896)(148.74)}{177.448 - \frac{5}{5}} \sqrt{\left[7.069 - \frac{34.763}{5}\right] \left[4461.1438 - \frac{22123.587}{5}\right]}$$

$$36. \quad \text{correlation coeff.} = \frac{(876.971)}{177.448 - \frac{5}{5}} \sqrt{[(7.069 - 6.953)][(4461.1438 - 4424.717)]}$$

$$37. \quad \text{correlation coeff.} = \frac{(177.448 - 175.394)}{\sqrt{[(7.069 - 6.953)][(4461.1438 - 4424.717)]}}$$

$$38. \quad \text{correlation coeff.} = \frac{2.054}{\sqrt{(0.116)(36.427)}}$$

$$39. \quad \text{correlation coeff.} = \frac{2.054}{\sqrt{4.226}}$$

$$40. \quad \text{correlation coeff.} = \frac{2.054}{2.056}$$

41. correlation coeff. = .999

A calibration that has a correlation coefficient of less than .990 is not considered linear and should be re-calibrated. As you can see from the worksheet we have 4 Qa numbers that are in the PM10 range (1.02 - 1.24 m<sup>3</sup>/min) and the correlation coeff. is > .990 , thus a good calibration. Next, calculate and record the SFR (sampler's seasonally adjusted set point flow rate in m<sup>3</sup>/min).

$$\text{SFR} = 1.13 [(Ps/Pa)(Ta/Ts)]$$

where:

SFR	=	sampler's seasonally adjusted set point flow rate, m <sup>3</sup> /min
1.13	=	designed sampling flow rate of PM10 samplers, m <sup>3</sup> /min
Ps	=	seasonal average barometric pressure, mm Hg
Pa	=	actual ambient barometric pressure during calibration, mm Hg
Ts	=	seasonal average temperature, K
Ta	=	actual ambient temperature during calibration, K

$$\text{SFR} = 1.13 [(757/753)(294/291)]$$

$$\text{SFR} = 1.13 [(1.005312)(1.0103092)]$$

$$\text{SFR} = 1.13 [1.0156759]$$

$$\text{SFR} = 1.147 \text{ m}^3/\text{min}$$

To be more accurate when using an average temperature and barometric pressure, it is better to use a daily, weekly, or monthly average instead of a seasonal average.

Then, calculate and record the SSP, sampler's seasonally adjusted recorder set point.

$$\text{SSP} = [m * \text{SFR} + b] [\text{Sqrt}(Pa/Ta)]$$

where:

SSP	=	sampler's recorder set point, recorder response
m	=	slope of sampler from linear regression
SFR	=	sampler's seasonally adjusted set point flow rate, m <sup>3</sup> /min

b = intercept of sampler from linear regression

Sqrt = square root

Pa = actual ambient barometric pressure during calibration, mm Hg

Ta = actual ambient temperature during calibration, K

$$SSP = [17.6685 * 1.147 + 8.9094] [\text{Sqrt}(753/294)]$$

$$SSP = [29.175169] [\text{Sqrt}(2.5612244)]$$

$$SSP = [29.175169] [1.6003825]$$

$$SSP = 46.69$$

The SSP is the design operating flow rate of the PM10 High Volume Sampler, 1.13 m<sup>3</sup>/min or 40 CFM, corrected to the current ambient temperature and barometric pressure. Adjust the mass flow controller to agree with the above determined SSP. This is done by loading the sampler with a piece of Micro-Quartz filter. Turn on the sampler and allow it to warm up to normal operating conditions. Adjust the mass flow controller set screw (turning pot) until the flow/pressure recorder reads 46.69. The sampler should now be sampling at the designed flow rate of 1.13 m<sup>3</sup>/min or 40 CFM, corrected to current meteorological conditions.

Tisch Environmental, Inc.  
PM10 High Volume Sampler Calibration

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                                SITE
Location-> Cleves, Ohio          Date-> 1-2000
Sampler-> TE-6070BL, TE-6070D-BL Tech-> Jim Tisch
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                                CONDITIONS
Sampler Elevation (feet)         400
Sea Level Pressure (in Hg)       30.05 Corrected Pressure (mm Hg)   753
Temperature (deg F)             70      Temperature (deg K)       294
Seasonal SL Press. (in Hg)       30.20 Corrected Seasonal (mm Hg)   757
Seasonal Temp. (deg F)          65      Seasonal Temp. (deg K)     291
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                                CALIBRATION ORIFICE
Make-> Tisch Environmental, Inc Slope-> 0.99486
Model-> TE-S025A               Intercept-> -0.00989
Serial#-> 3                     Date Certified-> Original
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Plate or Test #	H2O (in)	CALIBRATION		LINEAR REGRESSION	
		Qa (m3/min)	I (chart)	IC (corrected)	
1	5.45	1.475	56.0	35.00	Slope = 17.6683
2	3.40	1.167	47.0	29.37	Intercept = 6.9094
3	3.10	1.115	46.0	28.75	Corr. coeff. = 0.9998
4	2.90	1.079	45.0	28.12	SFR = 1.147
5	2.80	1.060	44.0	27.50	SSP = 46.67

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                                CALCULATIONS

Qa = 1/m(Sqrt((H2O)(Ta/Pa))-b)      SFR = 1.13(Ps/Pa)(Ta/Ts)
IC = I(Sqrt(Ta/Pa))                 SSP = (m*SFR+b)(Sqrt(Pa/Ta))

Qa = actual flow rate                SFR = sampler set point flow rate
IC = corrected chart response         SSP = sampler chart set point
m = calibrator slope                 m = sampler slope
b = calibrator intercept              b = sampler intercept
Ta = actual temperature (deg K)       Ta = actual temperature (deg K)
Pa = actual pressure (mm Hg)          Pa = actual pressure (mm Hg)
                                      Ts = seasonal temperature (deg K)
                                      Ps = seasonal pressure (mm Hg)

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For subsequent calculation of sampler flow:  
 $1/m((I)(\text{Sqrt}(T_{av}/P_{av}))-b)$

m = sampler slope  
 b = sampler intercept  
 I = chart response  
 T<sub>av</sub> = daily average temperature  
 P<sub>av</sub> = daily average pressure